Teller
October 1982

Comments on "Models, High-Energy Theoretical Physics
and Realism"

Everything I have studied in quantum field theory seems to fit Professor Cushing's description; physicists have recycled and stretched the fabric of their methods and theories, stiching on some incredible patches where the the fabric simply tears apart. But I have some questions about the moral we should draw from this. Cushing writes, "I ....feel that a case can be made for scientists as clever people who make their theories work, rather than as discovering laws of nature which preexist outside their own minds." (p. 7). But Cushing himself immediately qualifies this radical view: "Of course, not just any theory can be made to work," and he continues by analogizing theory building to tailoring a suit of clothes to fit a person. There is no unique suit, and none fits perfectly. "However, a bad fit is evident" (p. 7) But from the cut of the suit, we learn much about the shape of the body it covers, though of course in many respects we are misled. Similarly for theories. Rather than say with Cushing ~~initially~~ that scientists are clever people who make their theories work, I think we should say, in the spirit of his qualification, that they make THEORIES THAT WORK. There is all the difference in the world.

Either way, quantum field theory and S-matrix theory illustrate the fact that the success of theories turns on the exhaustive work of clever scientists. Focusing on this fact certainly does promote the skepticism Cushing feels about realism for theories. He concludes that "...we have no warrant for assigning truth or reality to [the constructs of our theories] with any meaning other than that they work (or really, haven't failed us) in fulfilling [the] functions [of empirical and calculational adequacy, and of giving us a stable means of organizing and comprehending our world]" (p. 29) "We may want more [hard nosed realism] from our theories, but this is the best we can do."(p. 30). To be sure, the theories in question have been almost entirely built on recycled analogies and expertise, and generalizations of prior techniques. To be sure, we aptly describe this process as one of stretching the old cloth to make it fit. And above all, one sensibly advises caution in saying that every bulge in the cloth covers some aspect of "reality" as opposed to arising as an artifact of the way we tucked and stretched the fabric. But if relativistic quantum theories seem especially patched and stitched together, I think all this shows is that this is the best we have done with the subject, not that this the best we can do. ~~Other theories have done better.~~ Other theories have done better, and in a way which makes a realist stance seem more natural, albeit in some kind of approximative

sense. Classical mechanics, genentics, astronomy and geology, to mention a few hardly seem like cloth stretched over the thin air of "phenomena". Do such theories come off with cleaner looking realist credentials because they are in some sense less basic?If so that would have to be argued. I have a simpler explanation of why quantum field theory and S-matrix theory do not now seem as naturally to support a realist interpretation. These theories are in a terrible state of flux. Moreover, as yet we have no grip on what these theories are telling us about how to conceive of the world. To mention Cushing's example, if we interpret creation and annihilation operators as describing actual processes of creation and annihilation of particles, the theory leads us to think of the vacuum as seething with an unbelievable flux of particles going in and out of existence. Cushing askes: "Is nature <u>seriously</u> supposed to be like that?" (p. 27) But this way of reading the theory is suspect in the extreme. I will go into the reasons why in a little more detail in commenting on Dr. Redhead's paper, but most briefly it has to do with the fact the particles occur only in superposition[1]. More generally, my whole discussion of Reheads paper will contitute an argument for the unsettled state of quantum field theory's interpretation, and at the end I will return

with a more specific question for Cushing which may clarify his stance towards realism. But in the meantime, if I have not badly misdescribed the situation, we have every reason to think that when such theories reach their maturity and receive a coherent interpretation they will support a common sense realist attitude.[2]

Notes

1. Robert Weingard (1982) has already discussed what really comes to the same intepretational problem applied to the virtual particles said to arise in interactions.

2) An attitude freed from certain metaphysical baggage traditionally pinned to the word "realism". I have in mind what Fine has called the natural ontological attitude (Fine , to appear) While Cushing states (p. 29) that he intends his view to be consistent with Fine's, other view he mentions in the same breath sound very different to me.

Teller
October, 1982

Comments on "Quantum Field Theory for Philosophers
(This draft contains only part of the material to appear in the published version)

Dr Redhead has done a marvelous job of introducing us to a vast array of interpretive problems in quantum field theory. Throughout his discussion he returns again and again to the question, what does quantum field theory tell us about what matter is really like; and at each appropriate turn he argues for the partial answer, quantum field theory is underdetermined between particle and field concepts. Until the end, that is. There another view comes to the surface, with the introduction of ephemerals, a view which in retrospect lurked not very far below the surface all along: More accurately, neither particle nor field concepts are really adequate to the needs of quantum field theory. I take it Redhead must hold something like this view, for otherwise there would be no point in introducing "a new category of entities"

Surely the puzzles of the theory indicate a need for new ways of thinking about matter. So Redhead has made an important and needed move which few have had the courage to try. I am sure too, that he would be the first to agree that our grasp of his new notion of ephemerals stands to be improved. By pressing the notion critically, I hope I will ultimately contribute to this goal. In the paper

to be published I will also comment on some more specific issues that come up along the way. Here time forces me to move immediately to the topic of ephemerals.

Just as Redhead states, quantum field theory, as hitherto interpreted, seems to describe the details of observable processes in terms of a continuous superimposed flux of creation and annihilation. He is troubled by the difficulty of describing this situation in terms of classically concieved particles - his continuents - which certainly should not pop in and out of existence quite that fluidly. I would add the worry that, except for input and outputs, these "particles" occur only in superposition with each other. So Redhead suggests a new category of things to bear the interpretive burden: ephemerals.

To help get a grip on the concept, consider the following model. You and I hold a rope by the ends. Each of us gives our end a shake, so that two bumps appear and travel from our hands towards the middle. The bumps briefly merge in the middle, "pass through each other" and continue down the rope. Ephemerals are like these bumps. Redhead says of his ephemerals: that they "...can be distinguished one from another at any given instant of time..," which our bumps can be, at least while separated. Redhead continues: "...but unlike continuents they cannot be reidentified as the same entity in virtue of TI at different

times..." Now, I begged an important question above in describing the bumps as "passing through each other" and continuing. Why say that the bump moving from left to right after the meeting in the middle is the same bump as the one moving from left to right before? We could with equal justice think of the bumps as bouncing off each other, identifying the one moving from left to right before with the one moving from right to left after the meeting in the middle. In particular, the bumps have nothing like Redheads transcendental individuality to carry the burden of the reidentification.[1] Redhead continues by saying that for ephemerals "...such reidentifications [are only] possible if notions of spatio-temporal continuity can be applied." Again, the same goes for our bumps. It is our being able, when we can, to follow a bump along, in much the same way in which we would follow the movement of a baseball, which induces us to identify a bump at one instant with the bump at the instant just before just a tiny distance away. Next, Redhead remarks that "...ephemerals... can be created or destroyed..," which is likewise true for our traveling bumps. Finally Redhead tells us that , "A collection of indistinguishable particles [ephemerals] is itself a <u>single</u> ephemeral. Our bumps also have this most important characteristic. When the two bumps meet in the middle, we do not have an intermingling of the two which both somehow retain their individuality. Rather we get one bump

to which the two prior bumps have somehow contributed, a little like two quantities of water flowing together to make one larger quantity.[2]

All of this merely spells out what Redhead already clearly states: "A moving field configuration (or 'wave' in classical physics would be an example of a reidentifiable ephemeral." I have taken the trouble with the details, however, because once we see it spelled out, we find it harder to avoid asking: How are

quantum waves

ephemerals different from waves? Most importantly, ephemerals satisfy some sort of superposition principle - this was the last characteristic, that if we pile together a number of ephemerals, we do not get a bunch of ephemerals in a heap, but one new, partless ephemeral. It is true that this qualitative description provides something less specific than the superposition principle of classical wave theory. We have not been told whether there is some quantity in which superposition is linear. In general, Redhead has given ephemerals a less specific description than we have of classical field configurations. But until someone characterizes ephemerals in more detail, telling us how they differ from waves, or perhaps how they constitute a generalization of the wave, or the field idea, we have no reason not to think that ephemerals are simply wave phenomena by a different name.

Possibly Redhead will object at this point. The fact that

we may cast ephemerals as waves just shows again the underdetermination of the theory between wave and particle, or some particle like concept. This seems wrong to me. The point of moving to ephemerals was that the particle concept failed in a radical way for quantum field theory. We grope for a replacement. But what we come up with as the replacement for particles, as what will do the work we originally thought the particles might do, turns out to be, insofar as it has been made specfific, just waves with another name. Putting the point bluntly, in attempting to interpret quantum field theory, even selfconsciously trying to hang on to as much of the particle concept as can be made to work, we find that the particle concept quite falls away in favor of fields!

This conclusion is shocking (though of course not original), and immediately a reason occurs for finding it suspect. While superposition plays an enormous role in non-relativistic quantum mechanics, there the particle concept surely holds a fully entrenched position, At any rate, I am not inclined to question this. But then, if my conclusion for quantum field theory is right, there had better be some difference between quantum field theory and non-relativisitic quantum mechanics which explains why the particle concept drops out of the one in a way in which it does not drop out of the other. I think there is such a

difference. Non-relativistic quantum mechanics has particle conservation: However many particles go in, the same number of the same kind come out. While the first thing one learns about quantum field theory is that particles may be created and destroyed, I suspect we do not generally appreciate how abandoning the particle conservation of non-relativistic quantum mechanics further undermines the status of particles in the theory. The point may be brought out by extending our rope model. Suppose that when we set up traveling bumps on the rope we always have the same number go out as went in. Furthermore, the bumps going in and coming out all have one of a small number of distincitive shapes, and for any number of a given shape that goes in, the same number with that shape come out. Even though strange sorts of things might happen in between, such a bump conservation would make it more natural to hang on to a principle of individuation of reidentifiable individuals, at least as one of the operative considerations. This is an important reason for holding on to a role for the particle concept, but it goes by the board as soon as we move to the case in which bumps of one shape may terminate in favor of new bumps of another shape, especially when this happens in just the way characterisitic of waves. But this is just what happens when we move from non-relativistic quantum mechanis to to quantum field theory.

I have arrived at a position diametrically opposed to the one we most often hear. Feynman diagram have proved so extraordinarily useful in using and teaching quantum field theory that expositors have taken them as their guide in non-technical expositions. Since Feynman diagrams appear to work entirely in terms of the particle concept, including depiction of exchange of virtual particles, the diagrams have fostered a habit of talking about the theory which [redacted] emphsizes the particle concept to almost the complete exclusion of the field concept. But such a presentation ignores the fact (which all these expositors know as well as they know their own name) that in a full description of a process, the Feynman diagrams occur only in a superposition of all the ones which can mediate between the input and output. This fact alone completely compromises application of the particle concept in quantum field theory at all points other than input and output; and in following the trail blazed by Redhead in attempting to salvage some role for a particle like notion, particles seem to give entirely away to description in terms of fields.

But this can't be right either. I myself just acknowledged that at least particles go in to an interaction and particles come out. And we continue to face the fact of the finite quantum of action, with its implication of some kind of discreteness. As for the first consideration, perhaps we ought to opt

for an S-matrix formulation, taking a rigorously non-realist attitude towards the S-matrix. I think that this is to say for the formalism of quantum field theory exactly what Bohr said about the state function of non-relativisitc quantum mechanics, at least if by "non-realist" we understand not that a realist's claims are false, but that they are contentless, in a sense to be explained.[3] I would be interested in whether Cushing feels that the lessons of methodology point in this direction, or whether this suggestion over-interprets his position. But such a non-realist stance strikes me as at least misleading, in that it dulls the appetite for an interpretive task which objectively needs doing. I prefer to quicken the appetite, by salting it with the apparently foolhardy claim that the particle concept plays no role in the interpretation of quantum field theory, at least between the inputs and outputs. I expect this claim to be disproved. But no one has done this yet. And an honest disproof will teach us all a great deal.

Notes

1) This is argued in greater detail in my "Quantum Physics, the Identity of Indiscernibles, and Some Unanswered Questions" (Teller, 1983)

2) This also is argued in (Teller, 1983)

3) I have spelled out these views in (Teller, 1982)

I Themes in the paper

- A. Touches on many baffling issues
- B. Returns again and again to question
  - 1) What does QFT tell us abou the nature of the constituents of matter
  - 2) Recurrent explicit theme: The theory is underdetermined as between particle and field concepts
- C. Underlying theme
  - 1) More accurately, neither concept, in classical guise, is adequate
  - 2) Surfaces explicitly only at the end with the introduction of ephemerals
  - 3) This must be the underlying view - otherwise no point to introducing "a new category of entities"

II.Overview of my response

- A. Surely the puzzles indicate a need for new ways of thinging about matter
  - 1) So Redhead has made an important and needed move, which few have had the courage to try
  - 2) He would agree that our grasp of our new category should be improved
- B. I will first comment on some of the specific points and arguments along the way
  - 1) In the hope I may help in further clarifying our thinking
  - 2) Neglecting many which
    - a) I simply agree with
    - b) Some I just don't understand
- C. Then I want to critically press the notion of ephemeral, hoping this will lead clarification and further detail

III. Comment on some of the arguments made along the way

- A. Is classical physical theory underdetermined between particle and field concepts?
  - 1) Redhead: can represent particles as field concepts, in terms of a field property of impenetrability
  - 2) But not yet the full classical field concept: No superposition
- B. Bearing of the classical limit.
  - 1) R. considers the possibility of driving a wedge between field and particle in terms of whether the classical limit of a description in QFT yields a field or a particle theory.
  - 2) Argues, "But because two theories have different sorts of classical limit should not invite us to treat them as fundamentally distinct when we do not proceed to the limit." Implication seems to be, difference in limit no reason to deny underdetermination between particle and field.
  - 3) This is too fast:
    - a) because classical fields may be superimposed and classical particls not, sharp distinction between classical field and particle theories
    - b) If each of these theories arise as limits of some underlying more exacting description, stands to reason that the difference in the limiting description must already manifest itself in the more exact theory
    - c) Must already be some hint or foreshadowing at the level of QFT
  - 4) We stand to sharpen our understanding of the interplay between particle and wave concepts in QFT, or of the more exacting conceptual distinction which will supperceed them, by studying the differences which manifest themselves as the difference between classical fields ~~and particles~~ in the limit.

and particles, and how this cruder distinction arises from the more exacting one in the limiting process

C. What can be made of the distinction between massive and massless fields?

1) R. considers the attemp to separate particle from field by apeal to mass/less fields distinction
2) Here he provides a badly needed counter to accepted orthodoxing in the physics community
   a) Held that photons cannot be localized, massive particles can
   b) This seems to be an "as is well known" of physics
   c) References to Sakurai, Peielrs, Rosenfeld
3) To amplify very slightly on one of R's remarks:
   a) If we try to localize a massive particle to within its Compton wave lenght we produce more particles of the same kind
   b) Due to particle indistinuishability, we cannot tell which is the original, which a new one
   c) Thus we cannot localize better than a Compton w.l.
   d) Photons, however can also be localized, if only inexactly
      i) experimentally, through correlations and known decay times
      ii) theoretically, also to within a wave lenght
4) Would be useful to have this set out in more technical detail, to set straing this mistaken "as is well known"
5) Implications, so underdetermination of QFT between field and particle descriptions?
   1) Certainly less of a clear cut distinction than has been thought.
   2) Still, masslessness means less localizability, and this might be found to be a relevant difference
   3) Would be good to work though the group theoretic considerations which R outlined for relveant interpretive differences.

D. Do quantum statistics speak against a particle apporach?

1) For clear reference worth agian outling the argument.
   a) two bosons and two possible states: give four possible combinations
      i) particles 1 and 2 both in state a
      ii) both in state b
      iii) #1 in state a, #2 in state b
      iv) #1 in state b, #2 in state a
   b) quantum statistics, and the communtation relations of QFT, refuse to count cases iii and iv as distinct.
   c) This seems to call into question whether we really have two distinuishabel particles here

[redacted]

2) R's first counter to this argument
   a) a change of basis substitutes for cases iii and iv one symmetric state and one antisymmetric state, both superpositions of case iii and iv.
   [redacted]
   b) The evolution operator preserves an initial symmetry or antisymmetry, a dynamical restriction
   c) So if we start with a symmetric state, there are only three accessible alternatives: i, ii, and the symmetric superposition of iii and iv.
   d) Thus, says R, a dynamical restriction, and not any issue about indivduality of particles explains the quantum statistics

3) This counter argument seems to assume just the view it sets out to undermine
   a) It works only by appealing to a superposition of two particles in two states
   b) In general, superpositions involve a problem of individuation - this is precisely what gives rise to the puzzles of the double slit experiment
   c) So the assumed superposition calls into question the individuatlity of the "two" particles, which is just what was at issue to begin with.

4) R's second counter:
   a) One can of course use particle lables in describing this situation, even in describing the superposition, though we cannot tell which lable attaches to which particle.
   b) "...but only an extreme form of positivism would hold that because we cannot tell which lable attaches to which particle, therefor we are compelled to give up a description which does ascri labels to particles."

5) The fact that we are not compelled to reject them does not show that a description using labels is a good one, or that the lables bear their usual intepretation
   a) One can give correct descriptions using all kinds of idle machinery.
   b) the fact that there is no conclusive proof that the machninery is without real significance leaves completely open the question of whether we have any good reason for thinking that the machinery does or does not give a a correct or good description of the real situation
   c) In the case at hand we still have to face the problem of quantum statisitcs; or alternatively the need for describing the situation using a superposition of allegedly different particles in different states seems to rob particle labels of their usual significance.

E. Do vacuum fluctuation phenomena argue for a field over a particle interpretation?

1) Since by definition, the vacuum state is the lowest energy state, free of particles in the Fock Space representation, there seems to be no room for an appeal to particles in describing the vacuum
2) But due to the commutation relations there are uncertainties in various quantities which give rise to observable phenomena in the vacuum state:
   a) It would seem that we can describe these only with a field description, so that the theory no long seems underdetermined as between particle and field descriptions

[redacted]

3) R argues
   a) A particle interpretation fails to describe vacuum fluctuation effects only if we limit the interpretation to to quantites which are diagonal in the particle representation.
   b) "This rules out by definition quanties like local field obseervables which create or destroy particles."
   c) "..in an <u>extended</u> particle interpretation which allows the possibility of particle creation and annihilation...we can still talk of a particle interpretation of vacuum fluctuations."
4) This involves interpreting C&A operations as description actual creation and annihilation of particles as we think of them
   a) This interpretation of C&A operators has become widespread, encouraged by the enormouly practical use of Feynman diagrams
      i) The diagrams seem to picture the actual creation and anninilations
      ii) Since such a picturing works so powerfully in using the theory, one falls into assuming that what the diagrams seem to picture represents what really occurs.
      iii) But this view of C&A operators problematic in the extreme:
   b) Problems with "received" interpretaion of C&A operators:
      i) Do not represent observable quantities - not even hermitian
      ii) If they somehow represent "processes", as opposed to observable quantites, this is a whole new category of physical interpretation, a new role of operators in physical description, which we do not at all yet understand
      iii) And is clearly problematic
      iv) Creation and annihilation operators for one kind of particle can be expressed as a superposition of like operators for another kind of particle, or particles in differnt states
      v) If we want to say that they describe real C&A of real particles we must say that the real C or A of one kind coincides with C&A of other particles, and not clear how to understand this
      vi) Not clear that this problem is any worse, or even distinct from problem of understanding the meaning of superposition in QM, but the problem is at least as bad, is unsolved, and a satisfactory process intepretation of these operators cannot succeed without clarifying these questions.

This now seems wrong to me. For states in Q.M. We have The statistical <u>or</u> The propensity interpretations to fall back on: but nothing like that is available for interpreting C&A operators when They characterize what <u>only</u> goes on in superpositions

5) Another related problem with R's extended particle interpretation:
   a) The particles that function in explanation of vacuum fluctuations occur only in superposition
   b) A particle in supperposition is hardly a particle in anything like the classical sense.
   c) Suppoerposition of two states of one particle already leads, in conjunction with the particle concept, to terrible puzzles in the case of the two slit experiment
   d) Supperpostion of more than one particle take us further still from the classical concept - complete loss of individuality.
   e) Worry that such an interpretation may be called "extended particle interpretation" by courtesy only.

F. Virtual particles:
   1) In this connection worth emphasising, in agreement with Redhead, a closely related point.
   2) Redhead: "Care should be taken not to read into the description in terms of virtual particles anything more 'concrete' than is warrented by the mathematics of solving a problem specified by the exact Hamiltonian..."
   3) More specificially, the same point about superpositions constitutes the, or at least a major barrier to viewing virtual particles as particles.
      i) The vps arise as internal lines in Feynmann diagrams
      ii) But these always constitues elements in a gigantic superposition
      iii) No barrier to interpreting fixed external lines, common to all elements of the superposition
      iv) But the variable internal lines, occurring only superimposed with others, hardly seem to represent anything like particles in the classical sense.
      v) This point made in more detail
         a)) in Weingard's PSA article
         b)) Understated perhaps in not emphasising the gigantic extent of the superposition
         c)) Which is spelled out a little in my Indescernibles paper.

vp = virtual particle

Also to be extended by marginal comment p. 4

G. A final related point.
   1) vacuum expectation phenomena may be related to the zero point energy
   2) In such a way that the phenomena may be construed as a manifestation of the zero point energy
   3) We may thus be said to observe the zero point energy
      a) Most striking example involves simply amplifying it
      b) Which has been done
      c) Case to be made for saying that we observe the zero point energy in no less a direct way than we observe electrons, let alone neutrinos
   3) But in another phase of the theory the zero point energy must be thrown away to prevent the theory from describing energies as infinite!
   4) a) I think this constitutes a new and even more troubling level of inconsistency than the one treated by the renormalization probram.
      b) For one kind of explanation we have to ignore zpe, for another take it to have observable effects
      c) This is as disconcerting as it would be for the renormalization program to say that, afterall, the bare mass itself could be observed.

zpe = zero point energy.

IV Ephemerals

A. Just as Redhead states

1) At least formally the theory seems to describe the details of observable processes in terms of a wild, superimposed flux of creation and annihilation.

2) No way we can describe this in terms of particles classically concieved

B. So R. Suggests a new category of things to bear the interpretive burden: ephemerals

C. To help explain the concept, consider the following model

1) You and I hold a rope by the ends
2) each gives the end a shake
3) two bumps travel from our hands towards the middle
4) Merge in the middle, "pass through each other" and continue

D ephemerals are like these bumps:

1) Ephemerals "...can be distinguished one from another at any given instant of time": the two bumps can, while separated be distinguished

2) "...but unlike continuants ephemerals cannot be reidentified as the same entity..."

a) I begged an important question above in describing the bumps as "passing through each other" and conitnuing.

b) Why say that the bump moving from right to left after the meeting in the middle is the same bump as the one moving from right to left before?

i) Could with equal justice think of the bumps as bouncing off each other, identifying the one moving from right to left before with the one moving from left to right after the meeting in the middle

In particular, nothing like TI to carry the burden of the reidentification.

ii) Point argumed in greated detail in my "indiscernibles" paper.

3) "..such reidentifications only being possible if notions of spatio-temporal continuity can be applied"

a) Certainly true for our bumps

b) At least before the meeting, the underlying causal process gives reason for identifying the bump at one instant with the bump at the instant just before just a tiny distance away.

4) "...empemerals ...can be created or destroyed..." - certainy true of our bumps.

5) "A <u>collection</u> of indistinuishable particles ephemerals is iself a <u>single</u> ephemeral"

a) Again true of our bumps

b) When the two meet in the middle, we do not have an intermingling of two which both somehow retain their individuality.

c) This point argumed at lenght in "Indiscernability..."

d) Rather we have one bump to which the two prior bumps have somehow contiubed, a little like two quantities of water flowing together to make one larger quantity.

E. All this is to spell out what R. clearly states: "A moving field configuaration or 'wave' in classical physics would be an example of a reidentifiable ephemeral."

F. The point of spelling out this example:
   1) Once we see it spelled out, we find it harder to avoid asking: how are ephemerals different from waves?
   2) Most importantly, ephemerals are subject to some sort of superpostion principle (point #D-5 above)
      a) True, less specific than the superposition principle of classical waves: we have not been told whether there is some quantity in which superposition is linear
      b) But clearly spuerposition nevertheless
   3) In general, R has given ephemerals a less specific description than we have of classical field configurations
   4) But until someone makes the characterization more specific, we have no reason not to think that ephemerals are simply wave phenomena by a different name.
   5) R might suggest: This is just the underdetermination of the theory between wave and particle, or some particle like concept
      a) Seems wrong:
      b) The point of moving to ephemerals was that the particle concept failed in a radical way for QFT
      c) In groping for a replacement we find ourselves with a concept, which insofar as it has been made specific, seems to be waves with another names
      d) Putting the point bluntly: In attemptin to interpret QFT, the particle concept weems quite to fall away in favor of fields!

G. Consideration of this conclusion
   1) This conclusion is shocking
   2) A reason for thinking it suspect.
      a) Superposition plays an enormous role in non-relativistic QM
      b) But there the particle concepets continues to play a vital role.
      c) If my conclusion for QFT is right, there had better be some difference between non-relativistic QM and QFT which explains this difference:
         i) Non-rel-QM has particle conservation: However many particle go in, the same number, of the same kind come out.
         ii) While the first thing one learns about QFT is that particles may be created and destroyed, I suspect we do not generally appreciate how this shift from the particle conservation of non-rel QM further undermines the status of particles in the theory
         iii) This point may be prought out by extending our rope model
            a)) Suppose that setting up traveling bumps on the rope we always had the same number go out as went in..
            b) Moreover, the bumps going in and coming out all had one of a small number of distinctive shapes, and for any number of a given shape that went in, the same number came out, [redacted]
            c) Even though strange sorts of things might happen in between, such a bump conservation would make it more natural to hang on to a principle of individualtion of individuals, as at least one of the operative considerations
            d) But when we move to the case in which bumps of one shape may terminate in favor of new bumps of another shape, in just the sort of ways [redacted] characterized by a wave theory, this important reason for holding on to a role for the particle concept goes by the board.

H. In conclusion of QFT

1) Feynman diagrams have led most expositors/to emphasize the particle concept to almost the conplete exclusion of the field concept

a synopsis of the argument here !

2) Following the trail blazed by R, I seem to have reached the opposite conclusion: field to the exclusion of particle.

3) But this can't be right either:

  a) At least particles go in to an interaction and particles come out.

  b) And there continues to be the fact of the finite quantum of action, with its implication of some kind of discreteness.

4) As for the first consideration, perhaps we ought to opt for an S-matrix formulation, taking a rigorously non-realist attitude towards the S -matrix

  a) I would be interest in whether Cushing feels that the lessons of methodology point in this direction, or whether this is to over interpret his position.

  b) I think that this is to say for the formalism of QFT exactly what Bohr said about the state function of non-rel. QM,

    i) If by "non-reaist" we understand not that a realist's claims are false, but that they are contentless, in a sense to be explained

    ii) This is spelled out in my"Bohr and the Projection Postulate"

5) I think this attitude is at least misleading, in that it dulls the appetite for an interpetive task which objectively needs doing

6) To quicken the appetite, let me salt our task with the claim that the particle concept plays no role in the interpretation of QFT:

  a) I expect my claim to be disproved

  b) But no one has done it yet

  c) An honest demonstration that my claim is wrong will teach us a great deal.